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ABSTRACT

This paper reports on the development and validation of an instrument for recording haptic exploratory behavior through detailed examination of exploratory search strategies of young children. Individual differences within age level were investigated, as well as the extent to which information processing capabilities for haptic perception are dependent upon developmental level, the stimulus properties of particular shapes, and hemispheric specialization. Subjects were 76 school children aged 53 to 89 months who were tested individually on identification of 3-dimensional tactual stimuli in the absence of any visual cues. A haptic perception box, with holes for insertion of hands, allowed the child to explore pairs of shapes (identical or different) in a series of tests involving five types of shapes: topological (familiar or unfamiliar) or Euclidean (curvilinear or rectilinear), or a combination of both. Haptic exploration and accuracy, highly correlated with traditional tests of spatial ability, were found to be clearly dependent upon the child's developmental level. Significant intra-individual and inter-individual differences were noted. Success on a task was found to be a complex function dependent upon developmental level, task requirements, procedural variations, stimulus properties and individual abilities, as well as on the concomitant interactions. Evidence in support of Gibson's theory of distinctive features is provided. Evidence on cerebral dominance was inconclusive. (BF)

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A DEVELOPMENTAL STUDY OF HAPTIC PERCEPTION
IN YOUNG CHILDREN*

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ABSTRACT

The development and validation of an instrument for recording haptic exploratory behavior allowed for a detailed examination of the types of exploratory search strategies 76 children, ranging in age between 53 and 89 months, exhibited. Haptic exploration and accuracy, highly correlated with traditional tests of spatial ability, were found to be clearly dependent upon the developmental level of the child. Of importance was the finding of significant intra-individual and inter-individual differences in haptic abilities and haptic exploratory strategies. Success on a haptic perception task was found to be a complex function dependent upon the developmental level of the child, the task requirements, procedural variations, stimulus properties and individual abilities as well as the concomitant interactions. Evidence in support of Gibson's theory of distinctive features is provided.

A DEVELOPMENTAL STUDY OF HAPTIC PERCEPTION IN
YOUNG CHILDREN

A growing body of psychological and educational research has been concerned with the investigation of the various physical dimensions (color, size, shape, texture, weight, and hardness) which form the basis of the child's daily perceptual discriminations. While vision has been the focus of most of the interest in perception, theories of perceptual development and perceptual learning have evolved to explain haptic perception¹ as well.

In several experiments concerned with understanding haptic perception, Piaget and Inhelder (1956) presented children age 2 - 7 with a variety of familiar objects and geometrical figures. Each child was placed behind a screen, haptically explored the objects and shapes and was then required to identify them from visual pictures or representations. Exploratory observations and accuracy were noted and a developmental trend defined by several ontological, sequential stages was proposed (Piaget & Inhelder, 1956). The characteristics of each stage may be summarized as follows:

Stage 0 Below Age 2;6:

No experimentation with hidden figures is possible.

Stage I-A Age 2;6 - 3;6:

The child finds familiar objects and recognizes them through relatively passive tactile explorations. The child simply grasps objects and responds to chance discoveries.

Stage I-B Age 3;6 - 4;0:

Shapes are explored as if they were three dimensional. Those shapes first recognized are not Euclidian (e.g. circle, square) but topological (e.g. open, closed, intertwined).

¹Haptic perception and tactual perception are used synonymously to mean the ability to recognize objects through active manipulation in the absence of visual stimulation. This term is also used synonymously with stereognosis as referred to by Laurendeau and Pinard (1970).

Stage II-A Age 4;6 - 5;0 (or 5;6)

Crude differentiation of rectilinear from curvilinear shapes is apparent while different rectilinear shapes (e.g. square, rectangle) or curvilinear shapes (e.g. circles, ellipses) are not differentiated among themselves. Tactile exploration remains global but the child makes use of "chance" indications as they are encountered. At a later point within this stage the child demonstrates a differentiation of shapes according to their angles and their dimensions. Explorations show clear signs of a search for significant clues to identity.

Stage II-B Age 5;5 - 6;0:

The child begins to be capable of differentiating Euclidian type shapes (e.g. rhombus and trapezoid). Crosses and stars begin to be distinguished from one another but many errors still occur in the representation of complex forms. Exploration becomes much more active although not always systematic.

Stage III Age 6;6 - 7;0:

This stage is marked by the child's methodological exploration and ability to distinguish between complex forms and simultaneously take account of order and distance.

Piaget and Inhelder see this group of experiments as proof of the genetic primacy of topological representations over Euclidian representations. The subsequent transition so that the child recognizes Euclidian objects can be explained in terms of perceptual activity; an increased coordination of many concentrations or touches upon the object. Thus, young children often display a lack of perceptual activity such that minimal exploratory movements of the fingers and hands are not sufficiently developed to allow for correct identification of objects. As perceptual activity increases with the child's developmental level, greater coordination and exploratory searching for significant details is thought to allow for a more accurate mental image to be formed, resulting in greater recognition of objects. Similar findings have been reported by Fisher (1956), Laurendeau and Pinard (1970), Page (1959), Peel (1959) and to some extent Lovell (1959), though they differ as to the age at which children attain the various stages as specified by Piaget. While topological shapes tend to be identified more easily than Euclidian ones, a comparison

between the identification of topological and Euclidian shapes with curved edges by Lovell (1959) yielded no significant differences. Yet it would appear from Piaget and Inhelder's finding that young children identify familiar objects, and some even correctly identify Euclidian shapes, that some such discoveries are made by chance (Piaget & Inhelder, 1956). Nevertheless these haphazard, unsystematic explorations may be providing useful information through some distinguishing or distinctive characteristics, a theory which has support in visual perception (Gibson & Gibson, 1955; Gibson, Gibson, Pick & Osser, 1962) as well as haptic perception experiments (Gliner, Pick, Pick & Hales, 1969; Pick & Pick, 1966; Pick, Pick, & Klein, 1967).

Developmental changes in haptic preferences for stimuli varying in form, size, texture, weight and plasticity have also been noted in the literature (Corah, 1966; Gliner, 1967; Gliner et.al.1969; Klein, 1963; Pick, Christy & Frankel, 1972; Pick & Frankel, 1973; Siegel & Vance, 1970; Suchman & Trabasso, 1966). Yet the literature is abundant with discrepant findings apparently attributable to either procedural and/or stimuli differences. These discrepant results are further compounded when comparing studies incorporating inter- and intramodal methodological designs with and without memory demands (Derevensky, in press a). Still further, Harris (1975) argued that hemispheric specialization may play a significant role in haptic information processing. He contends that if the information processed from hand to cerebral hemisphere occurs contralaterally, and if the right hemisphere specialization for visual-spatial perception holds equally true for haptic perception, then in tasks requiring spatial discrimination, one should expect significantly better performance by the non-dominant hand (for most people this would be the left hand). Several empirical studies suggest blind children and adults tend to rely more on their left hand in a Braille reading task (Hermelin & O'Connor, 1971a, 1971b; Smith, 1929).

As well, studies by Milner and Taylor (1972) and Witelson (1974) indicate that tactile information is more efficiently processed in the right hemisphere.

Past research has not clearly delineated the critical variables amongst a multiplicity of interacting factors which influence haptic perception of shape. While several studies have attempted to examine developmental changes in haptic perception, the limitations of their methodological designs have resulted in a lack of information regarding the interrelationships of several identifiable dimensions and their concomitant interactions which are associated with haptic information processing capabilities and patterns.

The present research was designed to provide a detailed examination of the haptic exploratory behaviors children exhibit, individual differences amongst children of the same age level, and to examine the extent to which information processing capabilities for haptic perception of shape appear to be dependent upon developmental level, the stimulus properties of the particular shapes utilized, procedural differences and hemispheric specialization.

METHOD

Subjects

The subjects were 36 boys and 40 girls with normal intelligence enrolled in a middle class school in Montreal. The sample contained 25 preschool (age range 53-62 months, $\bar{X} = 57$ months), 24 kindergarten (age range 66-77 months, $\bar{X} = 71$ months), and 27 first grade (age range 76-89 months, $\bar{X} = 82$ months) children.

Materials

The test apparatus consisted of a yellow wooden box containing two openings (covered by felt material). These openings allowed the child to insert his hand(s) into the box in order to identify the three dimensional tactual stimuli without any visual cues. The tactual stimuli (33 shapes) possessed either topological (familiar or unfamiliar) or Euclidean (curvilinear or rectilinear) characteristics or a combination of both (mixed) (See appendix 1).

Experimental Conditions

Throughout the experiment each child was given two shapes (first the standard followed by the comparison) and made judgements based upon his haptic exploration. On half the trials the shapes (standard and comparison) were identical, and on the other half they were different. Each child was seen in five, 24 - trial sessions, the five sessions representing the five conditions. Conditions differed as to the method of presentation of stimuli, in terms of the delay between the presentation of the comparison and the standard, and the hand(s) used for exploration by the child (See Table 1).

Insert Table 1 about here

Same-different judgements were based solely upon haptic exploration of both the standard and comparison stimuli. While the size of the shapes varied, the members of each pair of stimuli (standard and comparison) were approximately equal in size and area, the texture was identical and the order of the pairs of stimuli was randomized within each of the conditions. Testing under Conditions A and B were similar. The child haptically explored the standard stimuli and was then immediately presented the comparison stimulus to the same hand (right in Condition A and left in Condition B). In Condition C both the standard and comparison were presented simultaneously. In Condition D the child received the standard in his right hand, a six second delay was imposed, the comparison stimulus was then presented to his left hand. A six second interval was interjected in order to determine the effects of "short term" memory on haptic exploration as well as to determine its effects upon the child's exploratory behavior. This delay was selected rather than a shorter time period since it has been suggested that six seconds is sufficient to allow for the fading of a visual "icon" (Neisser, 1967). Since information processed visually is stored more efficiently than information processed haptically, a six second delay was used to ensure^a similar fading effect for haptically explored material.

In Condition E the standard was presented to the child's left hand, a six second delay imposed, followed by presentation of the comparison stimulus to the child's right hand. The average time for the 24 trials was 15 minutes.

Procedure

Each child was brought individually into the testing room and engaged in conversation in order to reduce any anxiety. Cerebral dominance was ascertained by noting the child's hand used in writing, throwing, and bouncing a ball. The child sat directly in front of the haptic perception box while the experimenter sat behind the box presenting the stimuli and recording the child's accuracy, haptic exploration and response latency. The experimenter began by saying: "(Name) we are going to play some games with this house (haptic perception box) today, but before we play this game I would like to show you something else." The examiner proceeded to visually present a square and rectangle to the child and queried - "Are these two objects the "same" or are they "different?" If the child looked confused the examiner queried "Are these two the same or not the same." If the child was correct the examiner responded by saying "very good". If incorrect he responded "look at them very closely, are they the same or not the same." If the child still failed to correctly indicate they were different, the examiner responded "O.K. Let's try another pair." The experimenter proceeded to visually present two more pairs of objects in a similar manner (square - square and square - triangle). Since all objects were of the same thickness, texture, and were of different colors, children were compelled to respond on the basis of shape.

Upon completion of the pretest the children were told:

Now I'm going to show you some more things two at a time, only this time you are not going to look at them, I want you to feel them. (The child was then instructed to place his hand or hands into the haptic perception box). Remember this is going to be a feeling game, no peeking. Can you see anything inside the box? O.K. Now here is what I want you to do. I'm going to give you things to feel two at a time, first one and then another one. I

want you to tell me if the two things are the same or different (not the same was interchanged depending upon the child's conceptual level). Feel the first one until you have a good idea as to what it's like. (The child was allowed a maximum time of 20 seconds for both the standard and comparison stimuli). As soon as you have felt it enough and have a good idea as to what it's like say "O.K." and I'll show you the next one (the comparison stimuli was then presented).

A six second interval was given between trials. For the remaining 23 trials the children were told:

Now here are two more things. Feel this one(standard) and now this one(comparison). Are they the same or different?

Children were not informed about the accuracy of their judgements but were told in a very general manner that they were performing well in all tasks. Each child was tested under all five Conditions (one per day), the order of presentation being randomized into four possible combinations (ABCDE, BACDE, ABCED, BACED).

Based upon the protocols provided by Piaget and Inhelder (1956), Laurendeau and Pinard (1970), and the scoring mechanism used by Hoop (1971), the author developed a haptic exploration scale ranging from minimal exploratory movements to complete and systematic exploration (See Appendix 2). Within each of the five levels there exists a classification of several types of exploratory movements, permitting the experimenter to record the level of the child's exploration as well as an actual description of the child's movements. This instrument underwent exhaustive field testing and revision. Inter-rater reliability (4 raters) was 91 percent agreement for global levels and 81 percent for movements within a level.

Upon completion of the haptic perception tasks, the following standardized and unstandardized tests were individually administered: a) Object Assembly - WISC-R (Wechsler, 1974); b) Block Design - WPPSI (Wechsler, 1967); c) Space Visualization - Southern California Sensory Integration Tests (Ayers, 1972).

e) Coloured Progressive Matrices (Revised Order) (Raven, 1956); f) Spatial Relations Test - PMA (Grades K-1 Revised) (Thurstone & Thurstone, 1963); and g) Modified Gottschaldt Embedded Figures Test (Gottschaldt, 1926). Tests were administered in a random order.

RESULTS

An analysis of developmental changes in haptic perception and accuracy can be seen in Table 2. An intercorrelation matrix confirms the data presented

Insert Table 2 about here

in this table indicating a high correlation between age and haptic perception ($r = .67$), age and haptic accuracy ($r = .59$), and haptic explorations and accuracy ($r = .76$). The observations of haptic explorations and data presented in Table 2 clearly suggest that in general, young children approach the paired-comparison task in a much different manner than older children. Young children's exploratory behaviors are haphazard and unsystematic, often gaining their information through chance discoveries whereas older children appear to approach the task in a purposeful, systematic and deliberate manner as if mentally mapping its shape. Yet, while it appears clear that both haptic scores and accuracy improves with age such that older children demonstrate more sophisticated, systematic and comprehensive explorations, differential haptic explorations were found at each level indicating considerable intra-individual variability with respect to haptic exploratory movements (Table 3). This is a most signifi-

Insert Table 3 about here

cant finding since past literature has suggested greater stability and the existence of a limited repertoire of haptic exploratory behaviors whereas the present research found tremendous intra-individual variability.

Haptic exploratory behavior and accuracy were also found to vary as a function of the imposed procedural conditions. A two way analysis of variance indicated a significant main effect for grade ($F(2,73) = 28.86, p < .001$), condition ($F(4,292) = 7.35, p < .001$) and a significant interaction between grade and condition ($F(8,292) = 3.81, p < .001$). While examining the mean accuracy scores for all children by grade level, it would appear that performance is best under Condition C, followed by performance under Conditions B, A, E and D (See Figure 1). Significant differences were found between Conditions A and

Insert Figure 1 about here.

B ($t(75) = 2.26, p < .05$), Conditions A and C ($t(75) = 2.66, p < .01$), Conditions C and D ($t(75) = 3.67, p < .001$), and Conditions C and E ($t(75) = 3.79, p < .001$). In addition, comparisons between Conditions A and B and Conditions D and E yielded a significant difference ($t(75) = 3.03, p < .01$). However, a strong interaction between grade level and condition ($p < .001$) clearly suggests that no well delineated conclusions regarding supremacy under any one of the conditions can be drawn without taking into account variations due to age and grade level.

The finding of an interaction of age and condition (procedural differences) is most important, for they bear on certain fundamental questions to which this research was directed. These questions concern: 1) whether simultaneous presentation of stimuli leads to greater accuracy than successive presentation with minimal memory demands; 2) whether exploration using the child's left hand is superior to exploration using his right hand; 3) whether the imposition of a 6 sec. delay between presentation of the standard and comparison stimuli would cause a significant decrement in accuracy; 4) whether initial exploration of the standard using the left hand followed by exploration of the comparison

stimuli using the right hand would be superior to exploration of the standard using the right hand followed by exploration of the comparison stimuli using the left hand. While the results suggest that the presupposition that haptic information processing under simultaneous presentation of stimuli is generally superior to successive presentation and that memory demands tend to impede accuracy for young children, superiority under each of the procedural conditions is a complex function highly dependent upon the development level of the child.

Form complexity, in terms of their geometrical properties was also found to significantly influence haptic information processing. A comparison of haptic perception for the topological, Euclidian and mixed shapes is presented in Figure 2. It should be noted that in Figure 2 the category 'mixed shapes' is based

Insert Figure 2 about here

upon only 3 comparison stimuli. However, clearly this Figure suggests that within the present research children between ages 4;5 and 7;5 exhibit a greater haptic facility for recognition of Euclidian shapes than for topological shapes. Shapes and pairs of stimuli with mixed topological and euclidean characteristics are the most easily recognized. Successful recognition is then followed by euclidean shapes and finally topological shapes.

It has been suggested in the literature that if information processed from haptic perception to cerebral hemisphere occurs contralaterally, and if right hemispheric specialization for visual spatial perception equally holds true for haptic perception, superior performance should occur when the nondominant hand was used. To test this hypothesis a multivariate analysis of variance analyzing grade and handedness on haptic perception scores (Table 4) yielded a non signifi-

Insert Table 4 about here

cant main effect for handedness within the five conditions, reaching only marginal significance for Condition C. A grade by handedness analysis was performed rather than an age by handedness analysis because of the limited number of left handed children ($N = 7$). However, haptic exploration in Condition B (left hand exploration) was superior to exploration in Condition A (right hand exploration) for all age groups. Accuracy in shape recognition tended to be greater under Condition B than Condition A. While the results tend to indicate a general superiority of left hand haptic perception the findings are not statistically significant.

Since the development of haptic perception clearly involves translating tactile-kinaesthetic impressions received from objects into a spatial image, standardized tests reported to have a high factor loading of k (spatial ability) were administered to permit analysis of the relation between haptic exploration and spatial ability. An intercorrelation matrix comparing various measures of spatial ability and haptic perception can be found in Table 5. Haptic perception

Insert Table 5 about here

appears to be most highly correlated with the Gottschaldt Embedded Figures Test ($r = .67$) and the Spatial Relation Test ($r = .66$). A correlation of .53 was found between the Block Design and haptic perception. Furthermore, it is interesting to note that the lowest correlations found with haptic perception were with the Form Perception and the Space Visualization tests of the S.C.S.I.T. While the Space Visualization test appears to have face validity for measuring spatial ability, its intercorrelations with the Spatial Relations and Gottschaldt Embedded Figures tests are extremely low. Since empirical support is available concerning the high loadings on a spatial ability factor for both the Gottschaldt Embedded Figures Tests and the Spatial Relations Test and none is available regarding the Space Visualization test, the face validity of this test may be

suspect and in need of further investigation.

Correlation coefficients between haptic perception and the Form Perception test were among the lowest ($r = .49$). This is noteworthy since the Form Perception test is an intersensory task requiring the individual to haptically explore a variety of euclidian shapes and to accurately identify them amongst a visual array of 12 euclidian shapes. It would appear that the indices of haptic perception used in the present research are better predictors of spatial ability than an intersensory matching task.

DISCUSSION

The results of the present research suggest that haptic perception (i.e. both haptic explorations and haptic accuracy) is dependent upon a) the individual ability of the child, b) the developmental level of the child, c) the complexity of the shape in terms of its geometrical characteristics and distinguishing features, and d) the demands incurred as a result of variations of the procedural condition. While accuracy scores on haptically perceived information were generally dependent upon the developmental level of the child, the haptic perception score (exploratory level) was found to be a better determinant of accuracy than chronological age. The significant intra- and inter-individual differences in search strategies found in this research have not been mentioned in the classic works on haptic perception reported by Laurendeau and Pinard (1970) and Piaget and Inhelder (1956) though they might now be inferred from the reports of Zaporozhets (1965, 1969). Protocols provided by Piaget and Inhelder suggest much greater stability of response than found in the present research, where procedural and task variables, in addition to individual abilities, seem to have contributed to the development within each child (independent of age) of a wide repertoire of exploratory behaviors. However, the variety of such behaviors did not preclude the emergence of a "preferred" modal level of

exploration which Piaget and his colleagues apparently regarded as the 'typical' behavior of a child at a given age level. Contrary to the literature, the finding of significant intra- and inter-individual haptic information processing precludes any delineation of finite, clear stages.

Procedural variations were also found to be of crucial importance. A significant main effect for age, condition, and interaction between age and condition suggests that while children process information more accurately as a function of their age, there exists a complex interaction with children at different ages performing differently under the various conditions. However, in general, performance under the simultaneous presentation of the standard and comparison stimuli was better than under successive presentation (with and without memory demands) especially for the high ability students, a finding in contradiction to Lavrent'eva and Ruzskaya (reported in Abravanel, 1968) who employed intersensory tasks.

While the results for children over 6;6 seem to indicate little difference in accuracy when a six second delay was imposed between the presentation of the standard and comparison stimuli, the performance of younger children (4;5 - 6;5) was found to be severely impaired when this delay was imposed. It is suggested that there may be a tendency for presentation of haptically perceived shapes stored in memory to be more inaccessible for younger children than for older children and/or that the younger children possess less information storing capabilities. Thus, if the young child lacks an effective representational system for storing haptically perceived information, short time delays may be sufficient for the child to lose the previously perceived information. These results cause one to suspect reports when the conditions of simultaneous or successive presentation are not clearly stated or when authors generalize their findings based upon either simultaneous or successive methods of presentation.

The results further suggest that young children exhibit greater haptic

accuracy with shapes having euclidian geometrical properties as compared with those possessing topological characteristics. This finding is significant since previous research has indicated that performance using shapes with euclidian characteristics should be exceedingly difficult for young children to correctly identify since their haptic explorations are unsystematic, limited and their general capacity for retaining and retrieving such information is minimal. The present findings clearly suggest that 'mixed' shapes are the most easily discriminated, followed by recognition of euclidian shapes and finally topological shapes. The superiority of haptic perception for euclidian over topological shapes was true for all children irrespective of age. This discrepancy may be explained in terms of different methodological designs. The present research incorporated an intramodal (haptic-haptic) model whereas Piaget and Inhelder (1956) and Laurendeau and Pinard (1970) used an intermodal (haptic-visual) design. Yet past research (reviewed in Derevensky, in press a; in press b) has clearly suggested intramodal haptic perception to be more difficult than intermodal haptic perception for young children.

A more important distinction arises between the stimuli used in the present research and those used in the Piagetian research. While the euclidian shapes presently used are quite comparable to those of the Piagetian research, the topological shapes were most probably not. Piaget and Inhelder incorporated topological forms which were generally marked by being quite irregular with many holes and jagged edges (e.g. toothed semi-circle, irregular surfaces pierced by one or two holes, open and closed rings, intertwined and superimposed rings) whereas the present research utilized topological shapes which were either irregular (puzzle pieces) or shapes of animals containing topological characteristics. In Gibsons' terms it may be that the topological shapes utilized by Piaget and Inhelder provided more distinctive and critical features in that jagged edges and holes in objects are more readily haptically perceived than curves, edges, proportions, this being especially true for younger children. Accuracy

for mixed shapes far surpassed recognition for both euclidian and topological shapes. Children age 4;5 - 4;10 were found to exhibit 80 percent accuracy on mixed shapes while having less than chance accuracy for topological shapes and slightly above chance recognition for euclidian shapes. This strengthens belief that Piaget's topological shapes provided many distinctive features within the meaning of Gibson's statement.

The superiority of recognition for euclidian shapes may require a reinterpretation of the distinctive features hypothesis. Previous researchers who examined this hypothesis have in general employed techniques of systematically varying one particular stimulus property (e.g. number of sides of objects). It is pointed out from the present research that it is more likely to be the interrelations between stimulus properties (e.g. perimeter, angles, curves, points) which is most interesting. Thus, while the topological shapes may have had more critical features, the euclidian shapes may have more "meaningful" and easier to detect (attainable through relatively unsophisticated haptic exploratory behaviors) critical features. The idea that euclidian shapes in the present research had fewer critical though more easily recognizable features seems quite plausible since these shapes had fewer contours, ridges, etc. but were more readily identified by the children. Following this line of reasoning, the more numerous critical features within the topological shapes may have caused an information overload (for example, in short term memory). Thus, rather than aiding the young child in his haptic discrimination it impeded him. While this hypothesis is speculative at best, it would be a most interesting one for further investigation.

The amount of exploration time (unlimited for each child) was also found to increase as a function of the child's developmental level. Thus, the critical features hypothesis tends to be further substantiated since a search for significant features by necessity requires significantly more time than haphazard

exploration. That children in general, and the older children in particular, spend less time examining the comparison stimuli than the standard, can also be explained in the light of the Gibsons' theory. Since the child was not aware of whether the comparison stimulus was going to be identical or different from the standard he was required to make a thorough examination of the standard. Once having stored this information the child could then proceed to examine the comparison stimuli. If he were only to detect or search for the "critical features" (dimensions of sameness and differences) within the comparison stimuli rather than making a complete comprehensive examination of all the features, this search strategy for the comparison object would generally take less time than the exploration of the standard. Thus, it appears that the recognition of particular stimuli depends not only on the haptic exploratory behaviors but upon the critical features of the individual stimulus as well.

A comparison of accuracy scores between Condition A (right hand exploration) and Condition B (left hand exploration) sought to test Harris' hypothesis that right hemisphere specialization for visual-spatial perception holds equally true for tactual perception as well. Underlying this hypothesis, and contrary to usual expectations about the superiority in ability when using the dominant hand, haptic perception and accuracy should be better using the nondominant hand. Accuracy scores for all children yielded a significant difference between Conditions A and B, with performance scores being greater under Condition B. The multivariate analysis using haptic perception and accuracy scores as dependent measures yielded a nonsignificant main effect for handedness. Furthermore, the univariate analyses suggests that children who apparently have left cerebral dominance as well as those children with right cerebral dominance perform equally well, both groups performing better under Condition B. Careful

inspection of the data and the nonsignificant univariate analyses suggests no significant difference between left-handed and right-handed children. However, due to the limited number of children with right hemisphere cerebral dominance this research is inconclusive.

The present study made use of several reliable measures of spatial ability to attempt to express haptic measurements in conventional ability terms. Haptic exploratory behavior and haptic accuracy had high correlations with tests of spatial ability. The better students (top 25%) performed significantly greater on tests of spatial ability as well as on the test of haptic perception. If their haptic exploratory strategies can be induced in others through an instructional intervention, this might prove to be a method of increasing spatial ability in children. However, only further research can determine the effectiveness of such instructional interventions both on haptic perception and spatial ability.

The foregoing research has provided much additional support for the theory of distinctive features as well as raising serious doubts about the methodology derived from intersensory perception applied to intramodal haptic perception. Issues have been raised concerning the ease or difficulty of recognition of shapes varying in their geometrical properties. It has raised questions concerning stability of haptic exploratory behavior and raises serious questions as to the generalizability of findings failing to account for results which are dependant upon the method of presentation of stimuli.

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Table 1
SUMMARY OF EXPERIMENTAL CONDITIONS

Condition	Method of Presentation		Delay Between Stimuli	Exploratory Hand(s)
	Simultaneous	Successive		
A		X	None	R
B		X	None	L
C	X		None	R and L
D		X	6 sec.	R then L
E		X	6 sec.	L then R

Table 2

MEAN ACCURACY AND HAPTIC SCORES FOR PRESCHOOL,
KINDERGARTEN AND GRADE ONE CHILDREN

GROUP	ACCURACY SCORE					HAPTIC SCORE				
	Condition					Condition				
	A	B	C	D	E	A	B	C*	D*	E*
Preschool (N=25)										
M	12.28	13.12	13.44	11.84	12.20	40.60	46.12	43.42	39.18	41.22
S.D.	2.79	3.14	3.53	2.54	2.57	14.49	16.61	17.76	15.66	13.28
Kindergarten (N=24)										
M	14.88	14.83	14.08	12.17	12.50	54.67	55.42	51.50	47.77	45.00
S.D.	2.25	2.85	3.20	3.80	3.08	15.29	17.59	15.93	19.92	20.48
Grade 1 (N=27)										
M	15.00	16.37	17.44	16.30	16.22	27.00	78.33	77.16	74.93	76.09
S.D.	2.37	1.80	2.62	2.20	2.28	18.34	17.76	19.20	22.49	19.22

* A t test revealed no significant differences between haptic score for the left hand and right hand under Condition C ($t(75) = .53$, $p = .60$), Condition D ($t(75) = 1.60$, $p = .55$), and Condition E ($t(75) = 1.79$, $p = .08$) thus the mean haptic score was used.

Table 3
 DIFFERENTIAL HAPTIC EXPLORATIONS FOR PRESCHOOL,
 KINDERGARTEN AND GRADE ONE CHILDREN
 Percentages*

Group	Level of Haptic Score				
	1	2	3	4	5
Preschool (N-25)	44.24	39.03	12.08	3.85	.80
Kindergarten (N-24)	30.46	36.79	27.74	4.71	.30
Grade 1 (N-27)	4.86	21.81	26.41	43.18	3.74

*Percent of total number of haptic explorations within each of the five levels of the haptic perception scoring sheet.

Figure 1

CORRECT RESPONSES AS A FUNCTION OF GRADE AND CONDITION

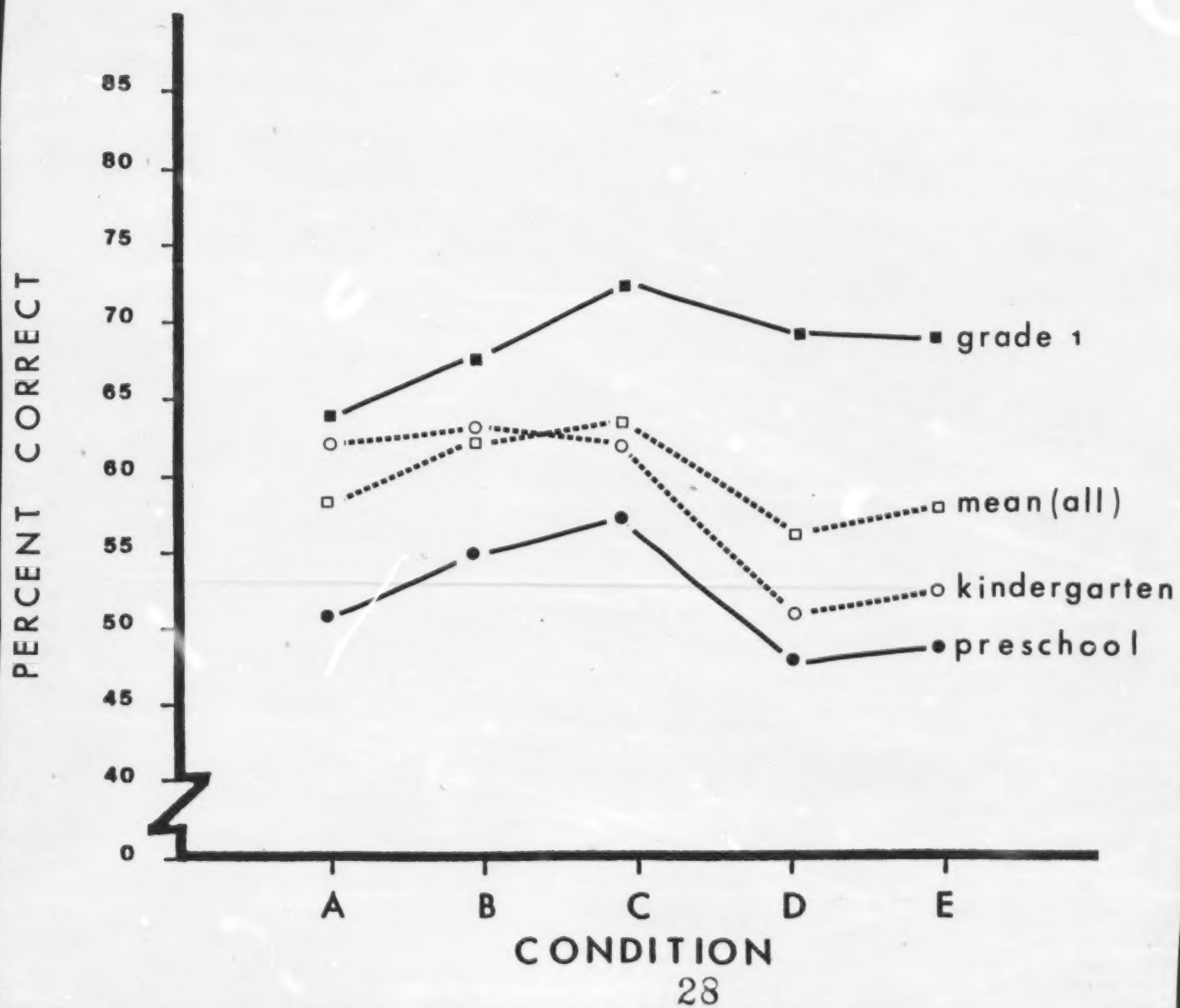


Figure 2
CORRECT RESPONSES FOR TOPOLOGICAL, EUCLIDIAN
AND MIXED SHAPES AS A FUNCTION OF AGE

T - Topological Shapes

E - Euclidian Shapes

M - Mixed Shapes

Age 1 (4;5-4;10)

Age 2 (4;11-5;5)

Age 3 (5;6-5;11)

Age 4 (6;0-6;5)

Age 5 (6;6-6;11)

Age 6 (7;0-7;5)

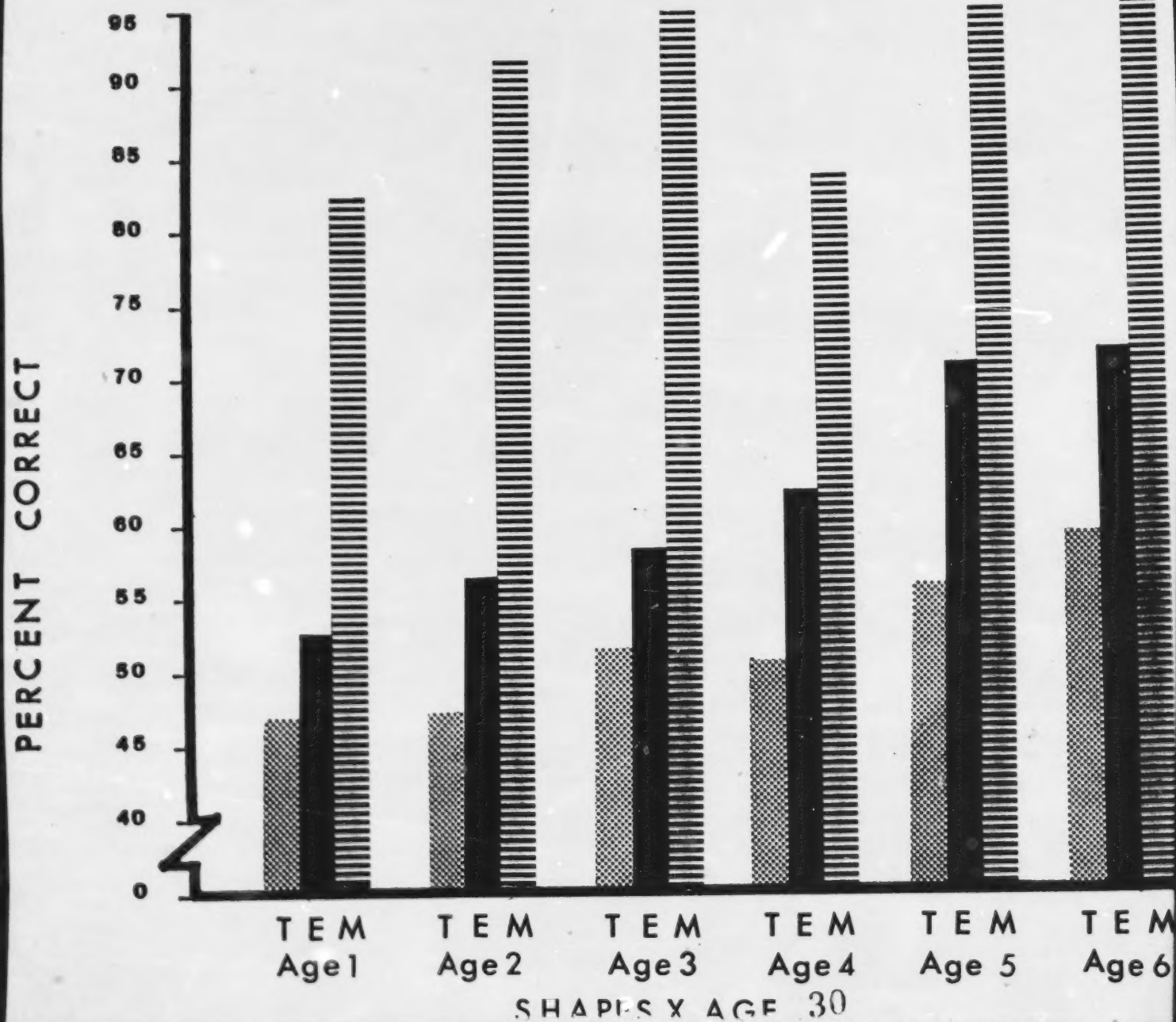


Table 4
MULTIVARIATE ANALYSIS OF VARIANCE FOR GRADE
AND HANDEDNESS ON ACCURACY SCORES

Source	df	Mean Squares	F	p
GRADE				
Multivariate	10,132		5.74	<.001
Univariates				
(1) Accuracy Cond. A	2	59.41	9.82	<.001
Error	70	6.05		
(2) Accuracy Cond. B	2	71.81	10.41	<.001
Error	70	6.90		
(3) Accuracy Cond. C	2	102.26	9.98	<.001
Error	70	10.25		
(4) Accuracy Cond. D	2	130.79	14.08	<.001
Error	70	9.29		
(5) Accuracy Cond. E	2	110.35	15.18	<.001
Error	70	7.27		
RIGHT-LEFT				
Multivariate	5,66		1.49	.25
Univariates				
(1) Accuracy Cond. A	1	8.30	1.37	.25
Error	70	6.05		
(2) Accuracy Cond. B	1	.14	.02	.89
Error	70	6.90		
(3) Accuracy Cond. C	1	27.54	2.69	.11
Error	70	10.25		
(4) Accuracy Cond. D	1	14.78	1.59	.21
Error	70	9.29		
(5) Accuracy Cond. E	1	1.52	.21	.65
Error	70	7.27		

Table 4 (Cont'd)

Score	df	Mean Squares	F	p
GRADE x RIGHT-LEFT INTERACTION				
Multivariate	10,132		1.38	.20
Univariates				
(1) Accuracy Cond. A	2	8.99	1.49	.23
Error	70	6.05		
(2) Accuracy Cond. B	2	9.45	1.37	.26
Error	70	6.90		
(3) Accuracy Cond. C	2	2.40		
Error	70	10.25		
(4) Accuracy Cond. D	2	4.24	.46	.64
Error	70	9.29		
(5) Accuracy Cond. E	2	21.04	2.89	.06
Error	70	7.27		

Table 5

PRODUCT MOMENT CORRELATION COEFFICIENTS BETWEEN AGE,
SELECTED STANDARDIZED TESTS, HAPTIC PERCEPTION AND ACCURACY SCORES

	1	2	3	4	5	6	7	8 ¹	9	10 ¹	11*	12*
1		.51	.54	.56	.77	.74	.48	.35	.49	.46	.67	.59
2			.60	.57	.65	.64	.35	.29	.44	.44	.52	.41
3				.56	.61	.71	.41	.35	.52	.42	.53	.54
4					.68	.68	.52	.47	.53	.50	.51	.44
5						.79	.52	.41	.48	.45	.67	.51
6							.49	.47	.53	.45	.66	.59
7								.83	.41	.39	.49	.46
8									.36	.37	.38	.46
9										.86	.46	.38
10											.36	.32
11												.77
12												

CODE: 1 = Age 2 = Ravens 3 = Block Design 4 = Object Assembly 5 = Gottschaldt Embedded Figures
6 = Spatial Relations (P.M.A.) 7 = Form Perception Total 8 = Form Perception Adjusted Score
9 = Space Visualization 10 = Space Visualization Adjusted Score 11 = Haptic Perception
12 = Haptic Accuracy

*The haptic perception score and accuracy score is computed by adding the respective scores in each condition and dividing by 5.

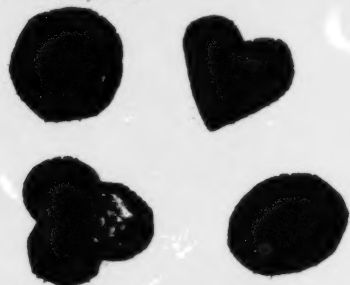
¹Adjusted scores are computed from the accompanying manual and incorporate reaction time
Probability: $r = .28$, $p < .01$; $r = .37$, $p < .001$

Euclidean

Appendix I
STIMULI

Mixed

31

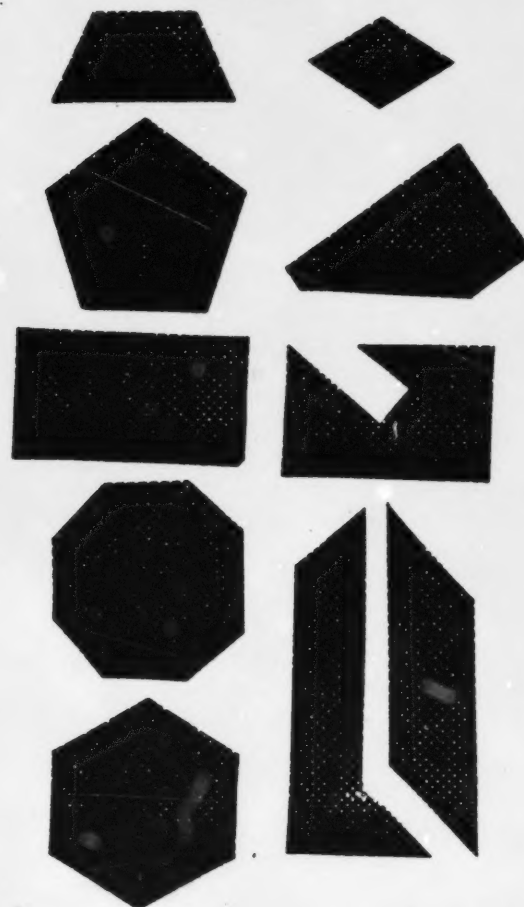


Topological



Topological

Euclidean



APPENDIX 2

HAPTIC PERCEPTION SCORING SHEET

1. One point is given for minimal movements. The child is to demonstrate at least one of the following for each object manipulated:
 - 1) Putting hand on the outside surface of the object as if wearing mittens; such as holding a ball in fist (but not exploring the edges of object with palms of hands or surfaces of fingers).
 - 2) Pressing hand flat against sides of object; rubbing object in the palm like a cake of soap.
 - 3) Feeling the surface of the edge with the palms of the hand (but not feeling the edges of object with the palm or active finger motions).
 - 4) Discovering a special characteristic of an object by chance, such as a handle or a hole in a topological form (but not actively searching for specific clues).
 - 5) Grasping object and turning it round and round (but not feeling the edges).
 - 6) Touching across diameter of object.
2. Two points are given for minimal, global and haphazard explorations of the object. The child must demonstrate at least one of the following for each object manipulated:
 - 1) Exploring haphazardly the edges of objects with the palms of hands and surfaces of fingers (but not systematically exploring the edges and specific features with the surfaces of fingers or finger tips).

- 2) Taking hold of at least two extremities to establish a relationship between the two; such as grasping the points of a triangle with two hands (but not exploring the recesses of the edges).
3. Three points are given for active manipulation of the object with incomplete motions. The child must demonstrate at least one of the following for each object manipulated.
 - 1) Searching actively for significant clues of objects such as curves, straight lines and angles with incomplete motions (but not following through on the entire object or carefully examining specific clues).
 - 2) Turning the object over and over in one direction, feeling the edges simultaneously.
4. Four points are given for active acquaintance and manipulation. The child must demonstrate at least one of the following for each object manipulated.
 - 1) Carefully examining all specific clues; such as putting finger in and around edges of a hole.
 - 2) Locating extremities of objects and exploring recesses of edges; such as feeling both points and inner angles of a star.
 - 3) Exploring the whole contour or edges with one finger tip or surface (but not using a starting point or reference point.
 - 4) Moving finger tips or surfaces of fingers around the edges and into the specific features.
5. Five points are given for operationalization or systematic exploration of an object. The only criteria for this is holding the object and outlining the object with a finger tip of the hand, starting and finishing at the reference point.